PERFORMANCE IMPROVEMENT OF THE CHeX FLIGHT CRYOSTAT

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ABSTRACT

The JPL flight cryostat last flew on the Space Shuttle in October, 1992 in support of the Lambda Point Experiment. A new experiment, the Confined Helium Experiment (CHeX), now in development will reuse this cryostat. An improvement to the cryostat performance was necessitated by the CHeX experiment having a longer mission requirement and stricter requirements imposed by NASA with respect to a launch-scrub turnaround scenario, The parasitic heat load reduction necessary to relieve both constraints was about 15% or 1 liter/day. The techniques implemented to achieve this goal, and subsequent results are presented along with a thermal model used during the analysis of the cryostat.

1NTRODIJCTION

The superfluid helium cryostat which provides the thermal environment to the JPL Low Temperature Platform (LTP) has flown on two previous missions, SpaceLab 2 in 1985 and the Lambda Point Experiment (LPE) in 1992 (part of the first United States Microgravity Payload, USMP-1). For these missions, the 10 day cryogen lifetime was sufficient to meet the requirements of the experiments it was supporting, given the launch-hold constraints of the time. This cryostat is next planned to be used to provide the cryogenic environment for the Confined Helium Experiment (CHeX) which is part of USMP-4 currently scheduled for launch in October, 1997. This experiment will measure the specific heat of helium in the vicinity of the lambda point in a geometry confined to two dimensions (SO μm spaces).

This cryostat is described in detail elsewhere and will not be described here."2 The essential features of this cryostat is that it has allowance for an 20 cm diameter x 90cm long instrument and holds up to 90 liters of liquid (defined by porous plug location) with an instrument of the size described above installed

For LPE, the cryostat was "grandfathered in" and allowed to have a 48 hour launch-hold. This was significant since the requirement at the time of the mission was 96 hours.

Launch hold is defined as the period of time between the nominal launch and the final launch attempt for a launch sequence. This launch hold value directly relates to the maximum time between last servicing of the cryostat and the subsequent servicing following a scrubbed launch. For LPE, this was 160 hours which the cryostat could meet with 8 hours

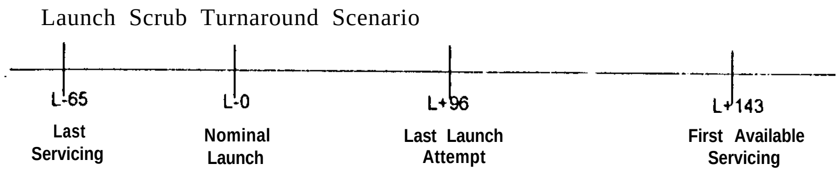

Figure 1. Launch-scrub-turnaround scenario for launch abort after 3 launch attempts

of contingency. CHeX, however, will have to meet the full 96 hour launch hold criteria. Thus the maximum time between servicing in the event of a launch scrub will be 208 hours, As inherited from LPE the LTP cryostat would be unable to meet this requirement while keeping the instrument cooled to 2K. The Launch-Scrub-Turnaround scenario is shown schematically in Figure 1. The CHeX science requirement for a "Minimum Mission" is for 7 days on orbit compared to the LPE requirement of 5 days. So that even in the event that the cryostat were grand fathered in and allowed the 4S hour lau nch hold, it would still require an improvement in performance to meet the science requirement of the new experiment, CHeX. The Minimum Mission scenario is shown schematically in Figure 2.

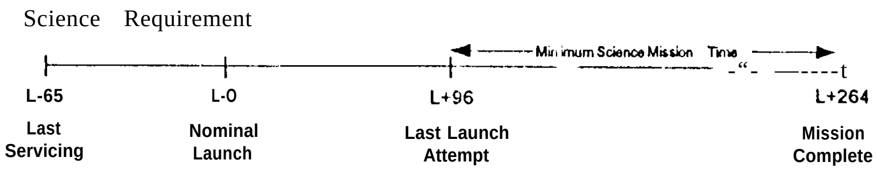

Figure 2. Minimum science mission scenario for CHeX

APPROACH

Any improvement to the cryostat was constrained to be a low risk, non-intrusive improvement. This meant that any hardware modification had to be accessible without significant disassembly of the cryostat and limited the possible modifications to those accessible though the neck of the cryostat (the end of the cryostat where the science instrument is inserted).

In its simplest form, the problem of cryogen lifetime is constrained by two values, the maximum fill volume and the parasitic heat rate. However, this problem had an additional parameter and that is the minimum volume of helium required to maintain the instrument at 2K while on the ground. This value is a balance of the amount of heat input to the instrument during a servicing operation and the cooling power to the instrument of the helium in the cryostat bath. The issues of maximum fill and minimum level are related to servicing techniques, while that of the parasitic rate is flight hardware related and subject to the aforementioned modification,

SERVICING ISSUES

A plumbing schematic of the LTP cryostat is shown in Figure 3. On LPE, the path for helium to flow for pre-cooling the external plumbing during a servicing operation was through V2, V4, and V6. During the initial flow of helium there was a significant heat input to the instrument, since the external plumbing, initially at 300K, had to be cooled prior to liquid flow resulting in some backflow of warm gas through the porous plug heating the portion of the instrument not covered by liquid. Parts of the instrument was seen to heat to a maximum temperature of about 5K in most cases. However, it was required that 25 liters of superfluid be in the cryostat prior to the start of an operation. Otherwise the instrument could get warmer than SK and put the superconducting shields on the high resolution thermometers of the instrument at risk of going normal.

To minimize the amount of heat input to the instrument during the initial phase of a servicing operation, we have simply chosen a separate pre-cool path. The path is through valves V2, V8, V7 and V6 shown on Figure 3. Since the CHeX instrument has not yet been installed in the cryostat it is impossible to say the exact effect of doing this However, worst case estimates with an instrument thermal-mechanical model mounted in cryostat have shown that the minimum level that should be tolerable is 20 liters. Several tests showed as little as 17 liters as minimum level. Using the new value of 20 liters, a 5 liter improvement over LPE is achieved, In terms of launch hold at the LPE parasitic rate of 7.5 liters per day this is a 16 hour improvement in hold time simply due to a procedural change.

The other parameter that can be affected by servicing is maximum fill. On LPE, the maximum till of superfluid helium at 2K was 78 liters (the maximum volume of the dewar given the porous plug configuration is 90 liters). This was achieved by pumping the supply helium down to about 100 torr and allowing it to flow at a maximum pressure differential of about 50 torr. The result was 90 liters of helium at about 50-60 torr which when pumped down to 2K yielded about 78 liters. We have only extrapolated this technique. By pumping the supply dewar down to just above the lambda transition and transferring helium at lower pressures we get a slightly higher fill fraction. When repeated serving operations are performed just after pumping the cryostat down to 10 torr and the supply dewar to 40 torr one can take advantage of thermal stratification in the dewar and achieve a significantly higher fill fraction of superfluid at 2K. We have found till volumes as high as 85 liters and as low as 80 liters at 2K by performing as many as 3 repeated operations and few as 1 extra operation. The more conservative value of 80 liters gives a 2 liter improvement in fill volume or about a 7 hour improvement in lifetime both on the ground and for flight, using the LPE parasitic rate. Each of these "improvements" were completely procedural and therefore posed no new risk to the hardware.

HARDWARE MODIFICATIONS

Visual inspection of the neck end of the cryostat was the first step in determining the appropriate course of action. The inspection revealed that there was very poor thermal

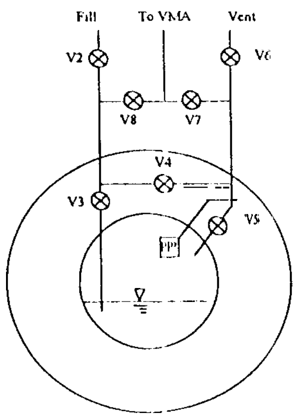

Figure 3. CHeX dewar plumbing schematic

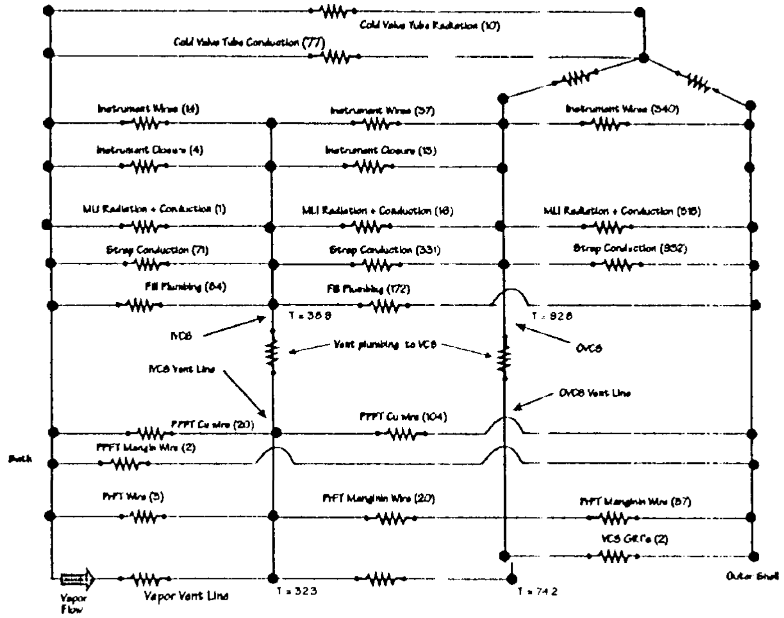

Figure 4. Heat flow diagram for the LTP cryostat in the LPE configuration

anchoring of all of the thermometry wiring from the warm interface of the cryostat to the thermometer. In some cases, the wires were attached to the vent line at a single point by Kapton tape. The inspection also revealed the use of copper wires for the current leads on a cryostat bath heater and on two superconducting liquid level sensors It was also noted that the attachments of the vent line to the vapor cooled shields were suspect. Finally, there was a clear 300K to 4K radiation leak for each of cold valves (V3, V4, and V5 on Figure 3).

Although the visual inspection was promising, the magnitude of the improvement that might be expected was not known. A simple thermal model of the cryostat as it existed for LPE was built. A node diagram, with predicted heat flows, of the model for the LPE dewar is shown in Figure 4. The model parameters were fit to the various measured temperatures and parasitic rates from LPE. Data for two outer shell temperatures with the bath at 2K and a 300K outer shell temperature with the bath at 4K were available and matched to the model. Areas which were not within the scope of the improvement were the MLI and the thermal sinking of the cryostat support straps.

The model showed that about 20mW of heat was being transported by the copper wires used for the cryostat heater and liquid level sensors. It was also noted that part of this heat leak was due to the poor thermal anchoring of the copper wires. All wiring was changed to 5 mil manganin wire with the following exceptions. The current leads on the cryostat heat were changed to 2-10 mil manganin wires in parallel and the current leads for the liquid level sensors were changed to 10 mil manganin. The wires were thermally sunk to the vapor vent line at six locations using copper spools soldered to the vent line and wrapping the wires to the spools. The wires were attached to the spools using epoxy.

The model also showed a significant temperature ditTerence between the vapor vent line and the vapor-cooled shields. These two were connected thermally by a series of 0.76 cm wide copper straps that are soldered on the vent line side and a bolted joint on the shield side. It is well known that bolted joints are thermally inefficient. We ran several tests on dry-bolted, greased-bolted and soldered joints. The soldered joints were made using indalloy solder with no flux and an ultrasonic soldering iron. Thermal conductance was

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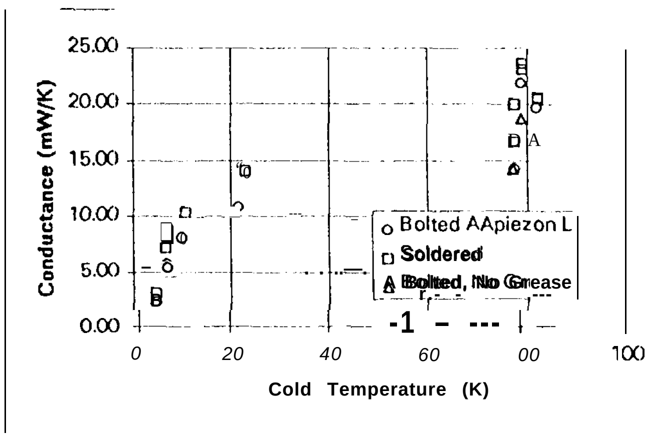

Figure 5. Conductance for various joints and cold temperatures.

outperforms

measured at powers up to 100mW across the joint and the results of the test are shown in Figure 5. Clearly, the soldered joints outperform the bolted joints over a wide range of temperatures. However, in lieu of removing all of the bolted joints, we chose to simply add as many straps between the VCS's and the vent line as possible. The ultrasonic solder technique was used where the strap attached to the aluminum VCS and tin-lead solder was used where the copper strap was attached to the stainless steel vent line. Great care was taken in managing the flux and cleaning all surfaces after the operation was complete so as not to impact the performance of the MLI.

It was noted from the model that the guide tubes for the warm actuators of the cold valves V3, V4 and V5 conduct a significant amount of heat. The tubes are made of and serve no other purpose other than to insure that these warm actuators do not snag the MLI in the cryostat when they are moved from their stored position to where they engage the cold valve (during servicing operations). Thus it was determined that a reduction in the conduction heat load would be achieved by simply slotting the guide tube with no increase in risk to the cryostat. This modification was made and resulted in a small reduction in parasitic heat load.

achieved

The thermal model used for the LPE system was modified for the changes described above with no instrument installed. The model was run and compared to experimental data. The details of the prediction are shown in Figure 6. A comparison of Figures 4 and 6 show a significant increase in heat transport from the vent line to the VCS's due to the additional thermal strapping added. A comparison of selected predicted results with experimental data is are shown in Table 1. About a 19% improvement was predicted while about 14% was realized. However, these data are with no instrument installed. Again using the thermal model of the cryostat, the thermal model of the instrument from the LPE simulation was added to the cryostat model and run. These results are also presented in Table 1. Clearly there is a significant parasitic load from the instrument which is not surprising given the wiring complexity and the more complex installation.

Table 1. Predicted and measured result with outer shell of cryostat at room temperature

	Measured, No Instrument	Predicted, No Instrument	Predicted with Instrument
Boil off (liters/day)	6.2	5.8	6.2
T_{IVCS} (K)	32	38	39
T_{OVCS} (K)	105	91	93

SYSTEM ANALYSIS

These results have not yet answered the question of whether this cryostat enhancement will meet the requirements for CHeX. For launch scrub turnaround the number of hours is given by:

LST = (Maximum Fill - Minimum safe level) /parasitic rate

Substituting 80 liters for maximum fill, 20 liters for minimum safe level and 6.7 liters per day for the parasitic rate, 215 hours is obtained which gives 7 hours of contingency on the 208 hour requirement, Although this is very little contingency, it represents a worst case analysis since the cryostat may be filled to a higher fill fraction and the minimum safe level for the instrument may be reduced.

The science requirement is for 7 days of experiment after sitting on the ground for 156 hours. However it is inappropriate to use the nominal ground boil-off rate for the entire volume of helium. While on the ground, with the tank moderately full there is an apparent steady state parasitic rate. As the volume of helium in the cryostat lessens, the. parasitic rate reduces. This is shown in Figure 7. Also it was noted during LPE flight that the outer shell of the cryostat was at a reduced temperature (273K) compared to the nominal ground condition (300K). The present thermal model predicts a reduction in parasitic load of about 0,3 liter/day due to this temperature reduction. Combining the two effects (Figure 7 and the reduced outer shell temperature) yields a predicted lifetime for the LPE flight of 12.1 days and is shown in Figure 8. The measured value was 12 days, 2 hours.

Figure 7 also shows boil-off data for the cryostat with the CHeX instrument installed. This was obtained by using the delta-boil-off due to the instrument from the thermal model

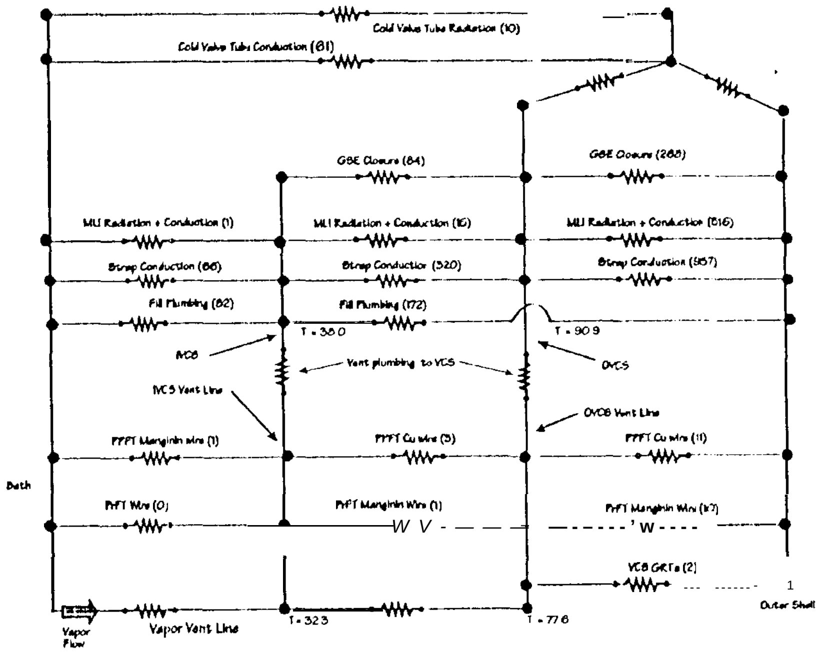

Figure 6. Thermal model with non-intrusive enhancements and no instrument.

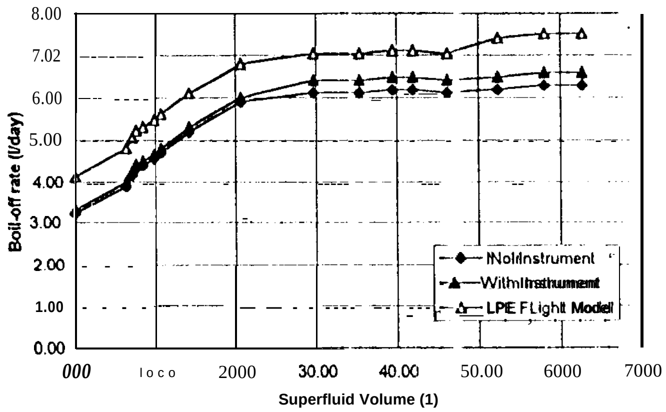

Figure 7. Parasitic rate as a function of liquid volume.

and adding it to the measured values obtained from the cryostat with no instrument present. For CHeX, the outer shell of the cryostat is expected to cool to 273 K as was seen on LPE. For the flight portion (time greater than the 96 hour launch-hold), the appropriate parasitic rate is the value shown in Figure 7, reduced by 0.3 liters/day due to the colder outer shell. The results of combining these data in this fashion are shown in Figure 8. The arrow indicates the remaining lifetime in the cryostat after 96 hours of launch-hold The value is 7 days with no contingency.

CONCLUSION

The enhancements to the LTP cryostat presented in this paper were twofold: procedural and hardware modifications. Combined it has been shown that this cryostat can meet the two modified requirements for the Confined Helium Experiment. The launch-scrub scenario, which required an additional 48 hours between servicing, is easily met with 8 hours of cryogen contingency. The science requirement for minimum mission, which required an additional 72 hours of on-orbit cryogen lifetime has been met, although with little to no contingency. Since the likelihood of actually launching the shuttle after a 96 hour

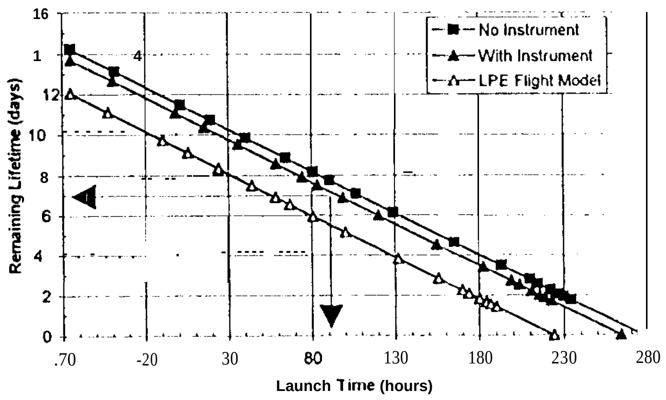

Figure 8. Cryogen lifetime versus launch time.

launch hold is very small, the project is not concerned with the small contingency. These data are based on experimental results with no instrument, and a predictive model for the cryostat and instrument. Final testing to verify these predictions will occur during the CHeX integration and test period scheduled to begin in January, 1996.

ACKNOWLEDGMENT

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